Multi-functional system for persons with disabilities using electroencephalography signals of eye blink

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Here we report a system which can be operated using electroencephalography (EEG) signals generated during eye blink and thus may be useful for persons with locomotive and other disabilities for performing their day-to-day activities. EEG signals are processed by a microcontroller and based on programming, the microcontroller takes a decision to perform the desired task by actuating a corresponding device from several devices connected to the system. An important feature of the system is that it can be adapted to particular needs of the user and can be attached/detached for actuation of different appliances according to the user's condition and requirements.

Keywords: Human–machine interface, electroencephalography signals, eye blinks, persons with disabilities.

PEOPLE with disabilities have to face many difficulties in their day-to-day activities. Recently, technological advances have been reported in various sectors. Technology is also helpful in developing assistive devices which help in lowering the sufferings of people with disabilities. Assistive devices are tools, products or equipment that help disabled persons or those with injuries to perform tasks and activities. Worldwide there are a significant number of such persons who are in acute need for assistive devices. Among these, a large number of people who are mentally fit but have restricted movements, speech and hearing problem, or a combination of multiple disabilities are dependent on others, even for performing small day-to-day activities. Governments of various countries have initiated many programmes to develop assistive technology for helping such people[1–3]. The main aim is to enable persons with disabilities to become integrated into mainstream society by educating and providing them the benefits of technology so that they may realize their full potential. In recent years conventional methods of human–machine interface have been improved using new emerging technologies along with increased computational power[4–9]. In one such attempt, the use of an infrared camera has been demonstrated to record eye blinks on real-time basis[10]. However, the technique has some issues: continuous exposure of IR radiation may damage the retina; detection efficiency decreases while switching on/off the lights at night, and recording is not possible if any obstacle is present in the image capture path[11]. In order to avoid these problems, use of electrical signals from the brain (electroencephalogram (EEG) or electrooculogram (EOG)) is proposed to facilitate human–machine interface[12–19]. Brain works like a processor for body control. Use of signals from the brain has been reported for controlling devices like switching on/off of lighting systems[12], assisted wheelchair[13], etc. Most of these systems are based on tracking the patient's eye movement by detecting their EEG or EOG signals. The eye-generated signals are suitable to operate devices. Also, eye movements are frequent. The procedure used for detection of EOG signals may be unsuitable, as the electrodes are used directly on the eye lids. It is also known that the EOG signals show extensive noise due to electrical activity of facial muscles[9]. On the other hand, EEG signals obtained from an intentional eye blink are clear and of higher magnitude than EOG signals[12]. They are easily generated with a little physical activity and are sensed externally using electrodes on the scalp. Non-invasive acquisition process of EEG signals is thus more user-friendly and suitable for human–machine interface[7].

Here we report a method of using EEG signals generated during intentional eye blink for the development of a system which can control multiple devices. A BIOPAC MP150 system is used for acquiring the EEG signals. The electrodes are placed in accordance with the 10/20 international system at the positions Fp1, Fp2 and C3. The acquired EEG signals are digitally processed using a band-pass filter with lower cut-off frequency $W_l = 8$ Hz and higher cut-off frequency $W_h = 22$ Hz. A Butterworth filter of order $N = 8$ is used. A notch filter of centre frequency 50 Hz is used to eliminate the interference noise introduced by power lines. Angles of complex conjugate zeroes require: $w_0 = \pm f_0/f_s\,(2\pi)$, where f_0 is the interference frequency and f_s is the sampling frequency[19]. Here $w_0 = 180°$ with $f_0 = 50$ Hz and $f_s = 100$ Hz. Hence coordinates of zeros are found to be $Z_1 = -1 + 0j$ and $Z_2 = -1 - 0j$; giving transfer function of filter

$$H(z) = 1 + 2z^{-1} + z^{-2}. \tag{1}$$

If signal and noise spectra overlap with each other, it is not possible to filter the signal using linear filtering process. Thus, signal obtained from notch filter is further processed by a moving average filter to remove random noise; thus giving

$$y_k(n) = x_k(n) + \eta_k(n), \tag{2}$$

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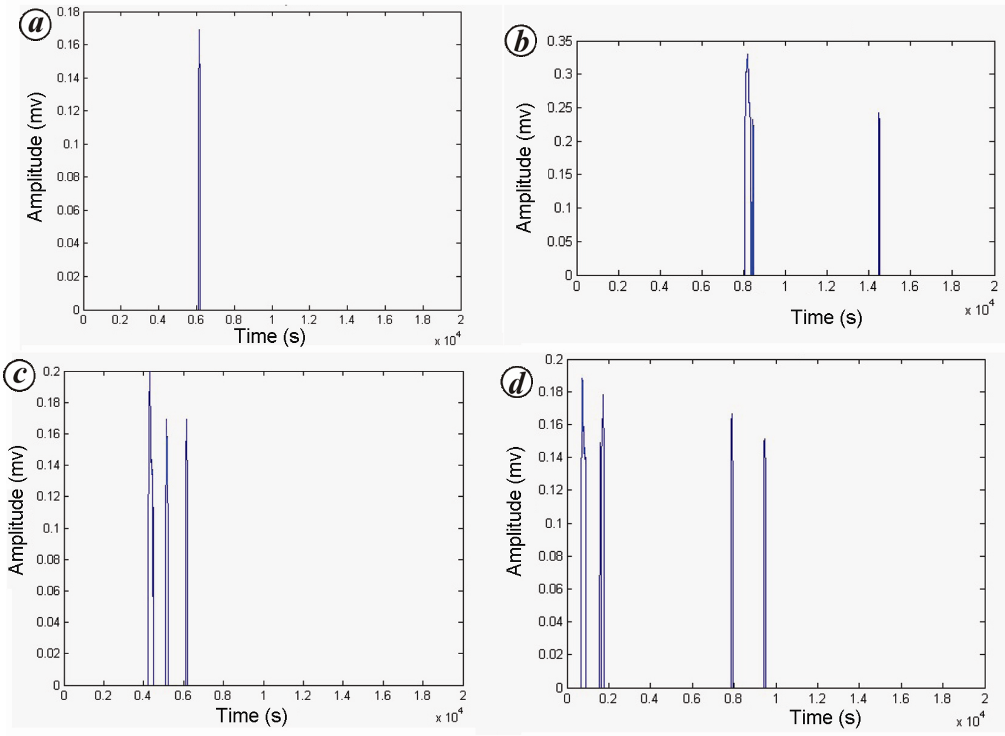

Figure 1 *a–d*. Processed electroencephalography signals corresponding to one, two, three and four blinks respectively.

where $x_k(n)$ is the original signal and $\eta_k(n)$ is the noise. Output signal corresponding to an input signal $x(n)$ is[19]

$$y(n) = \sum_{k=0}^{m-1} b_k x(n-k), \tag{3}$$

where b_k are filter coefficients and n is the order of the filter ($n = 5$ in our case). After applying z-transform, the transfer function $H(z)$ of the filter becomes

$$H(z) = b_0 + b_1 z^{-1} + b_2 z^{-2} + \cdots + b_n z^{-n}. \tag{4}$$

For fifth-order moving average filter, the transfer function becomes

$$H(z) = b_0 + b_1 z^{-1} + b_2 z^{-2} + \cdots + b_5 z^{-5}. \tag{5}$$

As EEG signals are non-stationary in nature, features must be computed in a time-varying manner[20,21]. The signal is processed to find the mean squared error $J(w) = E[e^2(n)]$, where $e(n)$ represents the estimation error[19]. A threshold voltage is set to eliminate unwanted signals and thereby to get accurate information about the position of eye blinks in the acquired signal.

Two consecutive intentional eye blinks are likely to be of the same amplitude. To actuate a device, if the subject blinks twice intentionally, followed by another unintentional blink as an after effect, then the difference in amplitude between the intentional and unintentional blinks will be significant. If the difference in amplitude between the two signals surpasses one-third of the prior blink, then it would be considered as a false signal and rejected by the system. This eliminates almost all the detections which occur due to unintentional eye blink. The digitally processed signal is fed to the timer T1 of the AVR Atmega16 microcontroller. For any incoming blink, the counter increments itself and checks for another consecutive blink. If another consecutive blink is counted, then the same function repeats; otherwise the preprogrammed task of one-blink detection is performed and the corresponding device is activated. A delay of 400 ms is given for checking consecutive blinks. In order to demonstrate and validate functioning of the system, the following tasks were assigned to different number of blinks:

(1) One blink: 'WATER' on LCD panel or run DC motor at 75% duty cycle panel.
(2) Two blinks: 'FOOD' on LCD panel or run DC motor at 85% duty cycle.
(3) Three blinks: 'DOCTOR' on LCD panel or run DC motor at 100% duty cycle.
(4) Four blinks: Master shutdown.

Execution of particular function depends on which device (display unit or DC motor) is connected to the system. We connected devices sequentially in our experiments. Figure 1 *a–d* shows the processed EEG signals corresponding to one, two, three and four intentional eye

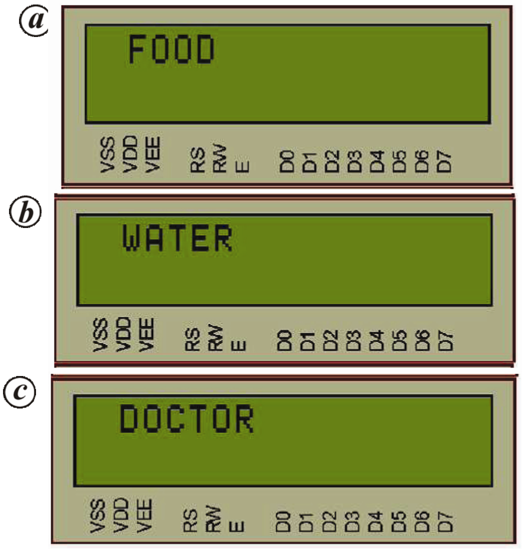

Figure 2. Messages displayed on LCD using different number of eye blinks.

blinks respectively. Actuation of devices by eye blinks is demonstrated by activation of LCD display and by running a DC motor. Figure 2 *a–c* shows messages 'FOOD', 'WATER' and 'DOCTOR' displayed on the LCD panel corresponding to detection of one, two and three eye blinks respectively. Speed of the DC motor was controlled in the laboratory using different number of eye blinks for different duty cycles of the motor and the same can be effectively used, for example, to control the speed of a patient's wheelchair. Further, different number of eye blinks can be assigned to different functions of the wheelchair like 'LEFT TURN', 'RIGHT TURN', 'FORWARD MOVE', 'BACKWARD MOVE', etc. These experiments clearly demonstrate that the system is suitable for human–machine interface and may be used for the development of devices that are helpful for persons with disabilities. The system allows a person freedom to control devices using his brain signals without any extensive training session. The same system may be used for multiple applications such as displaying messages, mobility, switching on/off devices like alarm device, bulbs, fans and controlling motor of a patient' bed, etc.

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